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No. 9

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AUSTRALIAN SOCIETY FOR LIMNOLOGY

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Edited by C. Max Finlayson

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PREFACE

The 1982 Congress of the Australian Society for Limnology was held in Griffith, NSW from 9-11 May. The theme of the meeting was "Limnological Consequences of Water Management." Three keynote speakers were invited to address different aspects of this subject. The keynote addresses presented by these speakers are reprinted in this issue of the Bulletin.

The assistance provided by Alan Chick in organising the 1982 Congress and preparing this issue of the Bulletin is gratefully acknowledged.

C. Max Finlayson

December 1982.

THE EFFECT OF LAND USE IN CATCHMENTS ON AQUATIC SYSTEMS: A CASE STUDY FROM WESTERN AUSTRALIA

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ABSTRACT

In the Peel-Harvey estuarine system of Western Australia, unacceptable accumulations of macroalgae (especially *Cladophora* and *Chaetomorpha*) have occurred on beaches of Peel Inlet since the mid 1960's. Since 1978 there have also been massive seasonal blooms of the blue-green *Nodularia*, especially in the Harvey Estuary.

Phytoplankton blooms are initiated in winter after high riverine nutrient inputs; the first blooms are of diatoms, and later (mainly in early summer) of *Nodularia*. Nitrogen and phosphorus are in part recycled in the system, supporting summer growth of macroalgae.

Uncleared forested catchments release low levels of N and P, but N concentrations in streams increase in relation to the proportion of catchment cleared. In contrast, P concentrations are low despite P fertilizer usage, except for the sandy soils of the coastal plains, which show high P export rates. Thus coastal plain catchments provide P loads disproportionately high when compared to their contribution to the water budget of the estuary. Emphasis is given to optimising the use of P fertilizers in agriculture.

INTRODUCTION

This paper is concerned with the effects on aquatic systems of plant nutrients derived from agriculture, and focuses on a case study which illustrates a number of the general principles involved. It deals first of all with the problems encountered in the system, and traces their origin to the catchments.

We are concerned with the Peel-Harvey estuarine system in Western Australia (Fig.1). This consists of two linked estuarine basins, which have comparable surface areas, and are some 2 m deep. A narrow inlet channel allows limited exchange with the ocean (Beer and Black 1979; Black *et al*. 1981), and the system is fed by three rivers (Serpentine, Harvey, and Murray), which have highly seasonal flows in the Mediterranean climate of the region. The town of Mandurah, near Peel Inlet, was until recently a quiet weekend resort and retirement area (population 12,000) but is now in a state of rapid urbanization. Much of the land near the system is being sub-divided for urban development, and canal

estates are being built or considered. On a holiday the bridge over the inlet channel is crossed by some 18,000 vehicles a day (Anon. 1982), and in the 1980/81 financial year licences were issued in the Shire for buildings with a cost of $25 M (Wainright 1982).

Fig. 1 The Peel-Harvey Estuarine System, Western Australia.

OCCURRENCE OF EXCESSIVE GROWTHS OF MACROALGAE AND PHYTOPLANKTON

Since the mid 1960's Peel Inlet (but not Harvey Estuary) has been affected by massive growths of macroalgae, in particular of the genera *Cladophora* and, especially in more recent years, *Enteromorpha* and *Chaetomorpha*. *Cladophora* and these other algae are blown onto what were once clean, sandy beaches, which may become foetid masses with a nauseous stench of hydrogen sulphide from the rotting algae. The algal accumulations are continually carted from the shores; in the 12 months from mid 1980, more than 5,400 m^3 were removed (Waterways Commission 1981). The problem is of great concern to residents and developers, and the algae clog the nets of fishermen and impede boat progress (Fig. 2).

Nevertheless, the system supports the State's largest estuarine-based fishery, producing for example in 1979, 700,000 kg wet weight, with a value of about $1 M (Lenanton 1979; R. Lenanton personal communication). Over the 10 years since the approximate beginning of the macroalgal problem, the commercial catch 'per unit effort' has more than doubled, while that in the nearby Swan Estuary has remained approximately the same (I.C. Potter and R. Lenanton personal communication). Thus a part of the increased productivity of the system appears to have flowed on to some individuals. In addition, large numbers of fish and crabs are taken by private individuals, and these do not appear on the commercial tables. For example, the number of shoes collected from beaches in the year 1980/81 by the Peel Inlet Management Authority, largely derived from amateurs catching crabs, amounted to no less than 1,104 (Waterways Commission 1981).

A second, probably worse problem concerns the seasonal occurrence of massive blooms of the blue-green *Nodularia*, which have occurred, especially in the Harvey, since 1978. The secchi depth is reduced to some 2 cm during a bloom under calm conditions (A. Huber personal communication), and is readily seen in

Fig. 2. Accumulation of macroalgae on the shores of Peel Inlet. Above, decomposing mass of *Cladophora* in the shallows, August, 1978. (Photograph courtesy D.M. Gordon.) Below, removing banks of *Chaetomorpha*, April 1981. (Photgraph courtesy of R.P. Atkins, Waterways Commission.)

LANDSTAT satellite imagery (Hodgkin *et al.* 1980). Fish and crabs appear to leave the Harvey during intense *Nodularia* blooms, and there has been at least one localised fish kill associated with a bloom (I.C. Potter personal communication). The distinctive smell of the alga, as well as the hydrogen sulphide generated when the alga rots on shore, is again offensive and environmentally intolerable. The shore accumulations appear exactly as described by Francis (1878) in his classical account of *Nodularia* in Lake Alexandrina.

SEASONAL CHANGES IN PHYTOPLANKTON AND NUTRIENTS

Fig. 3 shows time course data selected from a research and monitoring program which has been carried out since 1977. The 1977-79 data, along with

information about river flow (summarised below) and other physical data, have been the basis of detailed analyses of nutrient, salt and water budgets of the system (Black and Rosher 1980; Humphries and Black 1980; Humphries *et al.* 1981) summarised in Hodgkin *et al.* 1980. A longer time series is given in Lukatelich and McComb (1981), and will be discussed in detail elsewhere.

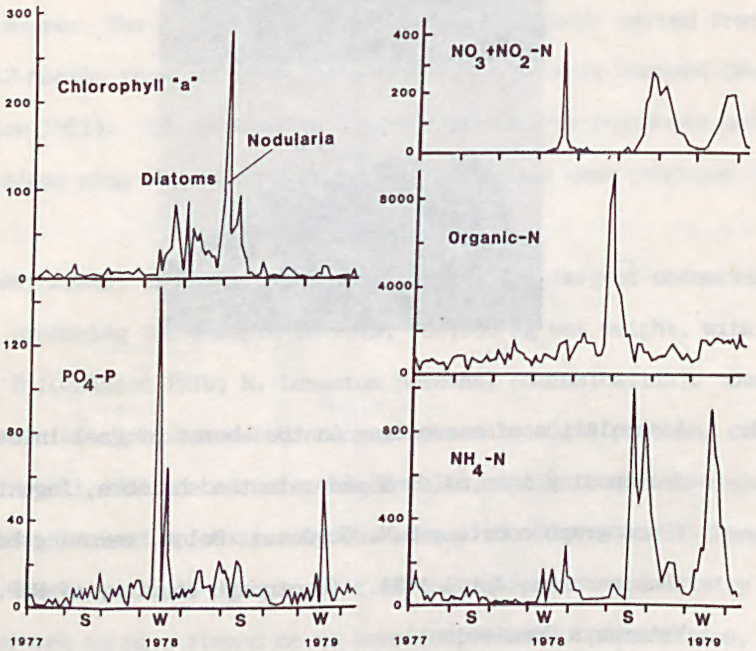

Fig. 3. Changes in chlorophyll and nutrients in the surface waters of the Harvey Estuary. All units are $\mu g\,\ell^{-1}$. (Redrawn from Lukatelich and McComb 1981.) S = summer, W = winter.

Phytoplankton blooms occur during most years, but not invariably. If they do occur, they are initiated as diatom blooms in mid-winter, when temperatures and light intensities are at their lowest. The diatom blooms collapse and are replaced by blooms of the blue-green *Nodularia*, which are most prominent in the Harvey, but may occur in the Peel as well.

Salinity ranges seasonally from some 5 to 45^{o}/oo, as compared with ocean salinity of 35^{o}/oo. These salinity changes are related to the highly seasonal input of freshwater in the winter period, high evaporation rates in summer, and limited exchange between the estuarine basin and the ocean (Black and Rosher 1980). Salinity depression *per se* is not sufficient to trigger off algal blooms - for example there were no significant blooms in 1977 and 1979 - nevertheless, the most massive blooms followed winters in which salinities were most depressed. In Fig. 4a, the maximum chlorophyll level reached during a particular year is plotted against the minimum salinity to which the estuary had fallen in the previous winter. Clearly the largest blooms occurred in those years when salinities had been most depressed by river flow, even though minimum salinity and maximum chlorophyll were separated by 15 weeks or so.

The key to the effects of the rivers lies in the nutrient contents of their waters. In 1979, a year in which the Murray flowed well, the concentrations of nitrate in Peel Inlet rose from a few $\mu g\ \ell^{-1}$ to almost 3000 $\mu g\ \ell^{-1}$ at some sites. Prior to this there had been a relatively low N:P ratio, hinting at nitrogen deficiency, but after this massive input of nitrogen the ratios altered dramatically, and clearly phosphorus had the potential to be limiting (McComb *et al.* 1981).

In the Harvey (Fig. 3), nitrate also rose in winter, but to much lower levels than in the Peel. Organic nitrogen concentrations rose at a time of phytoplankton blooms (Fig. 3), partly because of the uptake of nitrate by phytoplankton, and partly, in the case of *Nodularia*, by fixation of nitrogen from the atmosphere (Huber 1980). Ammonia, present at low levels in river water, is generated within the estuary by decomposition and sediment release, and rose to maximum levels after the collapse of an algal bloom; nitrate was subsequently produced in the Harvey, at a time of little or no river flow. The data provide evidence for the recycling of nitrogen in the system.

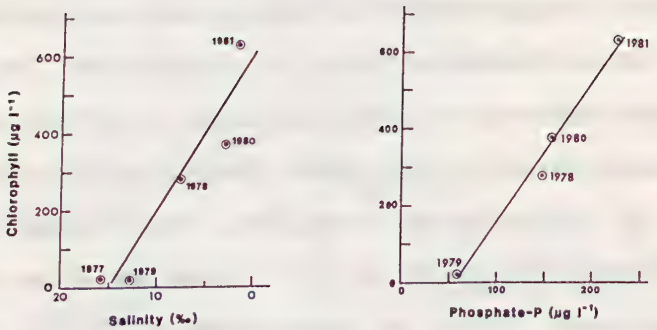

Fig. 4. The maximum concentration of chlorophyll in Harvey Estuary each year, plotted against (L) the minimum salinity, and (R) the maximum phosphate concentration, reached in the preceding winter.

Phosphate levels also change seasonally with riverflow, and are generally higher in the Harvey than the Peel, because of the relatively high levels of phosphorus in the waters of the Harvey River (see below), setting the scene for subsequent *Nodularia* blooms some 15 weeks later. Nevertheless, diatoms bloom first, in response to nutrient input. Total phosphorus levels were found to be more erratic than the other nutrient fractions, because the system is readily wind-stirred, especially in the Harvey.

In Fig. 4 the maximum chlorophyll of the *Nodularia* bloom is plotted against the maximum phosphate reached in the preceding winter. These data, in conjunction with data on N:P ratios and nutrient limitation bioassays (McComb *et al.* 1981) show that the water is generally phosphorus-limited, but transiently nitrogen-limited; nitrogen limitation would be corrected through nitrogen fixation by blue-greens (Huber 1980).

Despite the accumulations of algae on the beaches, much of the populations of these plants occur offshore in accumulated benthic beds. Fig. 5 summarises computer-based simulations of *Cladophora* growth rates at different times of year. The information is based on laboratory studies of effects of environmental factors on photosynthesis and growth rates (Gordon *et al.* 1980,1981A; Birch *et al.* 1981), but employs environmental data from the field (temperature, radiation, salinity, light attenuation coefficients, and nutrient levels). The timing of maximum and minimum growth is generally consistent with observations made in Peel Inlet, using populations of *Cladophora* imprisoned in perforated containers on the surfaces of the algal beds. Growth rate at the surface of an algal bed is at a minimum in winter, when light intensities and temperatures (c. 12°C) are low, and at a maximum in summer when light intensities and temperatures (c.25°C) are high. However, even a few millimetres into the bed there is a significant reduction of growth because of self-shading. Thus in a general sense light is of critical importance to the survival of benthic algae, and it is this need for light which largely precludes *Cladophora* from developing large populations at the floor of the Harvey, which is so readily wind-stirred and often turbid. Nevertheless, high nutrient levels allow the development of the large biomasses found in the Peel.

Now as pointed out above, only in winter are there abundant nutrients in the water, when light and temperatures limit macroalgal growth; in contrast, the levels of nutrients in the Peel in summer are low. The question arises as to how nutrients are transferred from the low-growth, winter phase to the high-growth, summer phase. The alga has been found to take up nutrients in 'luxury' amounts in winter, redeploying these for later growth under more favourable conditions. However, this mechanism would only maintain high growth rates for a relatively short time (Birch *et al.* 1981). Most of the summer growth is

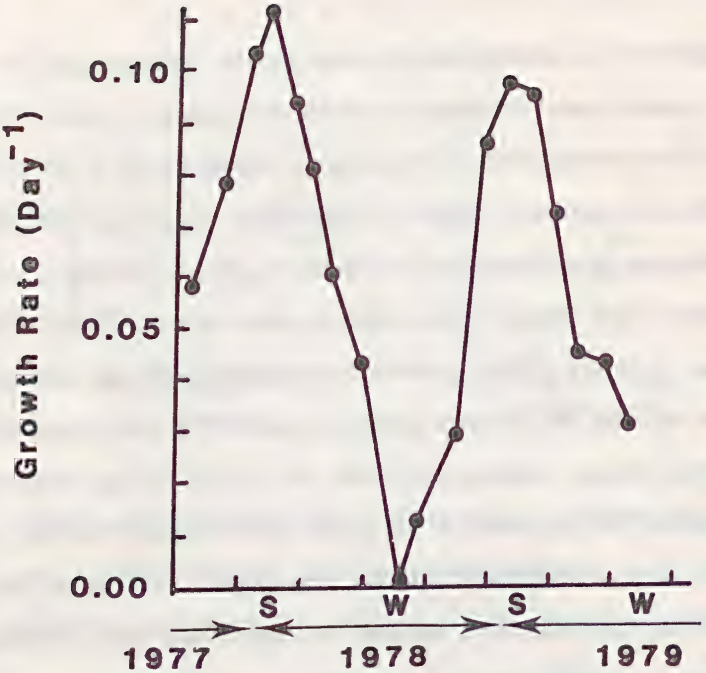

Fig. 5. A simulation of the growth of *Cladophora* at the surface of a submerged bed in Peel Inlet. The program was based on laboratory observations on growth and photosynthesis, but employs field observations on nutrient levels, light climate and temperature. S = summer, W = winter. (Redrawn from Gordon *et al.* 1981B).

supported by the recycling of nutrients from sediments and decomposing material within the algal bed, a pool of nutrients derived from decomposing macroalgae, and topped up by the input of sedimenting particulate nutrients (including phytoplankton). Phosphorus is of particular importance to the alga. It is usually present in the water at relatively low levels compared to nitrogen, and in contrast to nitrogen, phosphorus is typically present within the tissue of the alga at growth-limiting levels (Birch *et al.* 1981). The importance of phosphorus is also emphasised in modelling exercises concerned with the way in which Peel

Inlet may support large amounts of macroalgae (Hornberger and Spear 1970; Spear and Hornberger 1979; Humphries *et al.* 1979).

In overview, the nutrient input which allows the accumulation of a high biomass of macroalgae, and seasonal blooms of phytoplankton, is derived from the rivers in winter and in part recycled in the system. Of the nutrients, phosphorus is the most critical; relative deficiencies in nitrogen in the system are offset through fixation by blue-greens.

SOURCES OF RIVERINE NUTRIENTS

The catchments

The most striking geomorphic feature of southwestern Australia is a major fault line, the Darling Scarp, which runs north-south across what was once a flat plain carrying an ancient drainage system. Substantial movement along the fault ceased in the Cretaceous about 125 million years ago, though there may have been some movement in the late tertiary, about 20 million years ago. These changes left a relatively high inland plateau (280 m) carrying the ancient drainage system, with more recent rivers cutting back into the scarp and flowing across a coastal plain to the ocean. The land surface of the plateau is mainly highly eroded laterite. The coastal plain is covered in part by detrital material derived from the eroding scarp, but because of various marine transgressions during the quaternary, mostly covered by a series of ancient dune systems eroded back to low relief. The whole landscape - laterites of higher regions and sands of the plain - is heavily eroded and leached with very low native nutrient levels. (For an introduction to the geology and landforms of the area see Seddon 1972 and Mulcahy 1973, 1981).

Fig. 6 shows the undammed catchments of the three rivers which drain into the system, and the principal land uses in the catchments. The Serpentine and the Harvey Rivers are both dammed, and their remaining catchments drain the

predominantly sandy soils of the plain. These soils are readily waterlogged and flooded by the winter rains, and for this reason the Harvey catchment is drained for agricultural purposes. There is a small area of irrigated pasture in the south. On the other hand, the tributaries entering the Murray are largel undammed (total area almost 7000 km^2), draining from both inland areas of low rainfall and, nearer the coast, forested catchment.

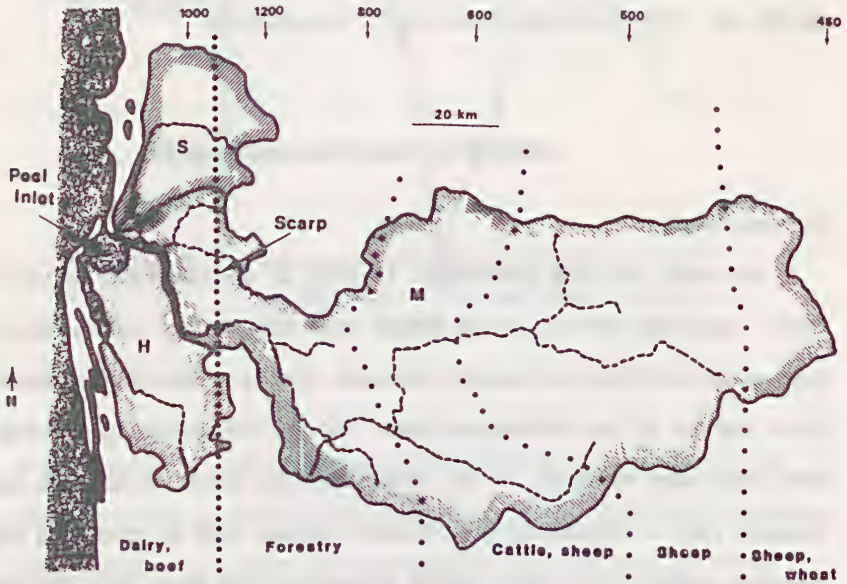

Fig. 6. The catchments contributing to the Peel/Harvey System. The areas shown are the undammed portions of H, the catchment of the Harvey River and associated agricultural drains which enter the estuary; S, the Serpentine River catchment; M, the Murray River catchment. The Darling Scarp separates the coastal plain from the higher inland areas. Numbers (above) show approximately yearly rainfall (mm), and principal land uses are shown below. Based on Black and Rosher (1980), Hodgkin *et al.* (1981), and Loh *et al.* (1981).

Natural ecosystems

The natural vegetation in the relatively high rainfall area of the plateau is jarrah forest (*Eucalyptus marginata*), carried on bauxite-rich laterite. The yield of water from the catchments is about 7% of what falls as rain, though the yield falls to about 2% in dry years (Black and Rosher 1980; Loh *et al.* 1981). Table 1 summarises information about a forested sub-catchment in the area. The amount of nitrogen and phosphorus entering the catchment in rainfall is compared with the amount leaving as stream flow, expressed per unit area. The catchment lost considerably less of these nutrients than the amounts which entered as rainfall, even though the total amounts of nutrients held in the forest vegetation are large; for example, some 10 kg ha^{-1} of nitrogen fell each year in litterfall alone. Rather more nutrients might leave in years of higher rainfall, or if a longer period had elapsed after fire. However, the data underline the generalisation that in natural ecosystems approaching an equilibrium or 'climax', the nutrient budget must in the long term balance, inputs of nutrients in short supply equalling losses, with a tightly controlled recycling of nutrients in the system. If this were not so, the community would not be in equilibrium with the environment.

Table 1. Nitrogen and phosphorus input and loss from the jarrah forest[1]

Nutrient	Amount (kg ha^{-1} yr^{-1})	
	Rainfall Input	Streamflow loss
Nitrogen	3.55	0.038
Phosphorus	0.30	0.0011

Year:	1979	Rainfall (mm):	777
Area (ha):	78	Streamflow (m^3):	8224

[1]Data from a jarrah forest catchment, draining into Yarragil Brook, 10 years since last burn. From Bell and Barry (1981) and personal communication.

Effect of clearing

Loh *et al.* (1981) have examined the nutrient concentration in water from 11 gauged sub-catchments of the Murray River basin, including one from the coastal plain. Fig. 7 shows the relation between nitrogen concentration and the percentage of cleared land in the catchments; nitrogen output has increased with clearing. The catchments differ in the purpose for which land has been cleared - orchards, crops, pasture and a piggery - and in the ratios between inorganic and organic nitrogen in their waters, but the general relation between clearing and concentration is a close one. As Loh *et al.* (1981) point out, in other regions of the world an increase in the nitrogen content of streams has been shown to follow increased agricultural activity, and is generally attributed to an increase in nitrogen fertilizer usage (e.g. McColl 1978; Ostrey 1982). While nitrogenous fertilizers are used in some of the catchments we are concerned with, our pastures rely for their nitrogen largely on subterranean clover. The conversion of organic material to more soluble forms may well play an important role in providing increased nitrogen levels in runoff; this mineralisation takes place during the spring and summer period in Western Australian soils, the late summer rains bringing about a rapid decrease in soluble nitrogen in the soil (Barrow 1969).

Thus, in addition to fertilizer application, it is to the increased use of pasture legumes over the past 30–40 years that we may look for an increase in the nitrogen content of streams draining pasture (Birch 1979).

Fig. 8 shows the results of the same survey for phosphorus; in contrast to nitrogen, the concentration of phosphorus in the streams does not depend on the percentage of clearing in the sub-catchments. Even though phosphatic fertilizers are used extensively in these catchments, the soils are able to retain much of the phosphorus, with the obvious exception of the only coastal plain catchment in the survey. This emphasises the ability of the gravelly, lateritic soils to bind phosphorus on clay, aluminium and iron oxide, and the inability of the sandy coastal plain soils to do so.

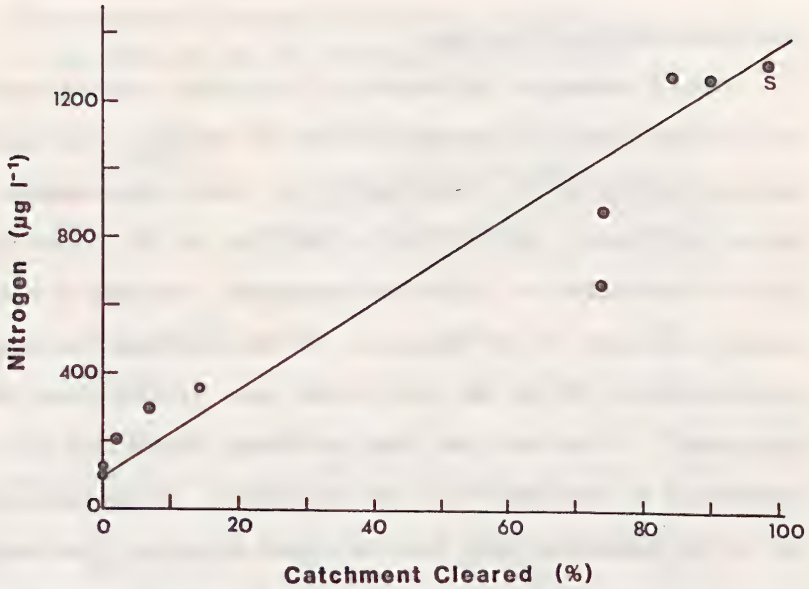

Fig. 7. The relationship between total nitrogen concentrations in streams and the proportion of land cleared in their catchments in the Murray River basin. S, a catchment on the coastal plain soils draining into the Serpentine River. Concentrations are flow-weighted means for the 1979/80 water year. (Data of Loh *et al.* 1981.)

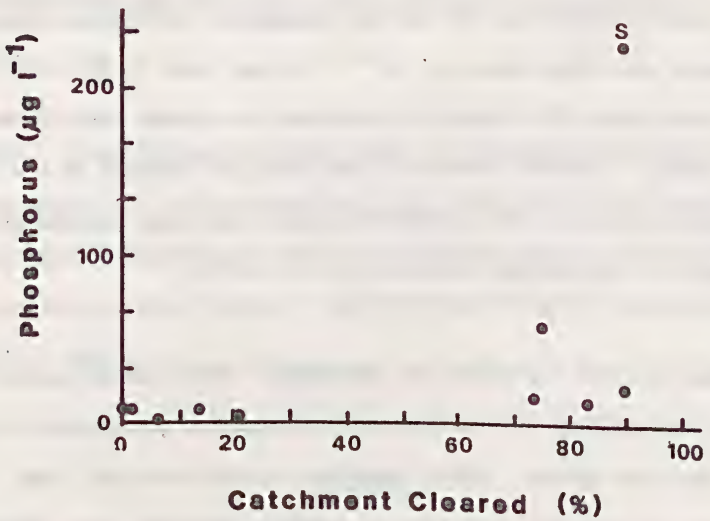

Fig. 8. The relationship between total phosphorus concentrations in streams and the proportion of land cleared in their catchments in the Murray River basin. S, a catchment on coastal plain soils draining into the Serpentine River. Concentrations are flow-weighted means for the 1979/80 water year. (Data of Loh *et al.* 1981)

Nutrients entering the estuary

Table 2 summarises the results of a separate, two-year study on phosphorus and nitrogen carried by streams entering the estuary. The data are expressed both as amounts and as a percentage of the total. For example, in 1978 the Murray contributed just over half of the flow and 73% of the nitrogen; but that year it contributed only 21% of the phosphorus, and much of that was from the coastal plain part of the catchment. On the other hand, although the Harvey contributed only 37% of the flow in that year, it contributed 60% of the phosphorus. In the next year, when the Murray flowed very poorly, the Harvey contributed no less than 76% of the phosphorus. It has been estimated that 90% of the phosphorus input from the rivers is derived from catchments cleared for agriculture, which comprise only 28% of the total undammed catchment (Black and Rosher 1980). Clearly it is to water from the coastal plain, and especially the Harvey and its associated drains, that one must look for the origins of the phosphorus. The coastal plain catchment is almost entirely cleared, and because the natural soils are so phosphorus deficient, there has been a great increase in the use of phosphatic fertilizers since about 1945 - the amount rose from about 5×10^{-3} t in that year to 27×10^{-3} t in 1973; the amount used then fell sharply in response to a price rise in superphosphate (Birch 1982). Limited historical data show an increase in the amount of phosphorus carried by the Serpentine River, and also confirm an increase in phosphorus in the estuary (Hodgkin *et al.* 1981).

There is some dependence of phosphorus export on the amount of phosphorus applied, but much of the variance in the exported phosphorus is not accounted for by this one factor. Other important factors are soil type, time of fertilizer application, and type of farming practice - all of these are under investigation at the present time. The amount exported is on average about 6% of that applied, though it reaches as much as 19% in some areas of the catchment

Table 2. The transport of water and nutrients in the three rivers entering the Peel/Harvey estuarine system[1]

	Total Amount	% Contribution		
		Murray	Serpentine	Harvey[2]
1978				
Discharge	560 x $10^6 m^3$	51	12	37
N	1586 t	73	7	20
P	121 t	21	19	60
1979				
Discharge	291 x $10^6 m^3$	29	19	52
N	510 t	22	21	57
P	67 t	6	18	76

[1]Data from Black and Rosher (1980), Hodgkin *et al.* (1981)

[2]Includes associated agricultural drains which enter the system direct.

(Birch 1982). These figures contrast with the generalisation of Vollenweider (1971) that some 1-5% of phosphorus applied to catchments is exported. (Indeed, under experimental conditions, even higher rates, ranging up to 80%, have been reported for the surface layers of certain sandy Western Australian soils; Ozanne *et al.* 1961.)

GENERAL

The information reviewed here provides a clear example of the effect of catchment fertilizer application on aquatic systems. It would be naive to suggest that the solutions to such eutrophication problems can be simply implemented. In principle, solutions might centre around increasing the loss

of nutrients to the ocean; removing the accumulated nutrient bank in the vegetation and sediments of the estuary; and reducing the level of phosphorus entering from the catchment. The last of these alternatives is the most attractive on general grounds, because it involves improved watershed managment and optimisation in the use of phosphatic fertilizers, of which there are only finite supplies.

The Australian Government has recently accepted the challenge of the World Conservation Strategy (IUCN 1980), and has arranged for the preparation of an Australian Conservation Strategy. The World Conservation Strategy has as one of its three specific objectives "to maintain essential ecological processes in life support systems (such as soil regeneration and protection, the recycling of nutrients, and the cleansing of waters), on which human survival and development depend". One of the stated priority requirements is to "ensure that the principal management goal for watershed forests and pastures is protection of the watershed", and to "ensure that the principal management goal for estuaries... and shallows critical for fisheries is the maintenance of processes on which the fisheries depend".

Of course management is likely to be complicated by many competing uses, which may be as or more important than the fisheries; in our example the raising of livestock and crops in the catchment, the quality of life for local residents, and the recreational value of the estuary. Nevertheless, such uses need not be incompatible, and in seeking compatibility a high priority must be given to optimising the use of phosphorus fertilizers in agriculture.

ACKNOWLEDGEMENTS

I am indebted to a number of colleagues, with whom concepts have been developed over the years, and who in several instances have allowed me to quote

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WATER QUALITY CONSEQUENCES OF INDUSTRIAL AND URBAN DEVELOPMENT - AN AUSTRALIAN PERSPECTIVE

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ABSTRACT

In the last 10 to 15 years the objectives of water management in Australia have undergone considerable change. Previously the purpose of water management was to provide adequate water of good quality for domestic, agricultural and industrial use. Today, in addition to these uses, water quality management aims to provide suitable water for recreation and to conserve aquatic life. These new objectives present a more difficult problem since standards in recreation and conservation are difficult to define.

There is a dependence by water management authorities in Australia on water quality standards and data developed in Europe and North America. These may be applicable in many parts of the country but in other areas differences in ambient water temperatures and seasonal patterns of rainfall indicate that they may be inappropriate.

The management of water is substantially in the hands of State and local government bodies. However, there is an urgent need for co-ordination and co-operation at a national level to achieve an adequate level of research into peculiarly Australian requirements in water management.

A National Water Research Institute is needed which can be guided by a national consultative body drawn from managers, researchers, etc., so that there is a representation of different regions throughout the country. A funding scheme based on water users, akin in principle to research levies on wheat and wool, should be developed.

INTRODUCTION

All societies, particularly advanced societies, are dependent on a plentiful supply of water. Large quantities of water are required to operate industry, agriculture and for domestic purposes. For example, it takes 848 000 litres of water to produce one man's woollen suit (Costin 1971).

Water engineering has a long history. Ancient Rome with a population of about one million, had a comparatively sophisticated water supply and sewage system. In fact, the huge Roman aquaducts still remain in many parts of Europe and are one of the most visible remaining reminders of that civilisation.

It is interesting to note that per capita consumption of water in ancient Rome stood at about 113 litres per day whereas contemporary western societies consume water at the rate of about 389 litres per day per person.

In the middle ages plagues of water-borne disease were very common. Thus disease control was one of the earliest objectives of water pollution control activities. The industrial revolution brought a host of new problems for water quality management. Urban complexes grew on an unprecedented scale resulting in the production of huge quantities of urban waste in areas of very limited size. In addition there was a need for improved quality and supply of domestic water for these large centralised populations. Industry brought with it the use of a wide variety of new substances for the manufacture of iron ore, clothing, food and so on. Thus the quantity and complexity of pollutants being discharged into waterways increased dramatically throughout the industrial revolution and that process continues today.

WATER MANAGEMENT OBJECTIVES DURING URBAN AND INDUSTRIAL DEVELOPMENT

Gilmour (1975) has reported that in Melbourne during 1836 with only 224 inhabitants, concern was expressed for the quality of domestic and industrial water supply. This water was drawn from the Yarra River but by 1843 the river was showing signs of pollution and unsuitability for these purposes. Later, in Victoria and other parts of Australia, acts of Parliament were passed to control pollution of waterways. In addition, engineering works were undertaken to treat waste water to a standard suitable for discharge. An example of one of these early engineering achievements is the Werribee Waste Water Treatment Plant, south-west of Melbourne. It is important to note that the objectives of water quality management during this period were to protect water for use by primary and secondary industry and for domestic purposes.

The maintenance of water quality for domestic, agricultural and industrial use has proved amenable to management by physico-chemical and related methods. Quality is usually defined by chemical and microbiological criteria whereby standards, usually in terms of concentrations or numbers, are set and the supply managed so that the standards are met. The standards for these purposes are the same for most countries throughout the world since the uses differ little from country to country. In addition the range of organisms, man and domestic animals, affected by the use of this water is limited. As a result this approach has been highly successful although it is possible that more subtle and less obvious problems remain to be resolved in this area.

The newer uses which have sprung up in recent years, recreation and conservation, pose a more difficult problem. The reasons for this are outlined below:

Water Quality Standards:

Recreation involves socio-economic factors which complicate setting standards of the kind outlined above. Also this area involves aesthetic factors which show considerable variation from individual to individual and considerable variation according to the recreational use involved.

Long Term Effects:

For successful conservation the aquatic ecosystem must be capable of surviving indefinitely. Thus in this case we are concerned with long-term effects of water constituents and water quality factors on aquatic ecosystems. With the information available at present it is difficult to predict the effects of <u>any</u> trace pollutant on <u>any</u> aquatic ecosystem over the long-term, e.g. 10-15 years. Even if it were possible to predict the long-term effects on specific organisms, the secondary ecological effects on other organisms in the systems would prove an even more intractable problem.

Quantitative Measures of Ecosystem "Health":

With the conservation management problem outlined above it is necessary to develop quantitative measures for the "health" of an aquatic ecosystem. But in fact there are very few satisfactory measures of the health of aquatic ecosystems which take into account seasonal variations and other similar factors.

Non-point Pollution Sources:

A significant proportion of pollutants from urban areas come from limited but non-point sources which are difficult to control. Thus water quality management here involves land use patterns and city planning.

New Chemical Pollutants:

The introduction of new industries is a process which started in the industrial revolution and continues apace today. Many new industries involve new processes and new chemical pollutants are produced. In fact, at present about 40,000 commercial chemicals are in use and each year some 2,000 new chemicals are introduced (Schmidt-Bleek and Haberland 1980). The ecological and water quality effects of those likely to enter the aquatic environment are not particularly well understood. The Organisation for Economic Co-operation and Development (OECD) involving some twenty-five industrial countries throughout the world has embarked on a program of new chemical registration. Australia is a participant in this program and it is expected that new chemicals will have to undergo testing and registration procedures before use will be permitted in the future (House of Representatives Standing Committee on Environment and Conservation 1980). This procedure will assist in controlling toxicants in industrial discharges.

SOME SPECIFIC URBAN AND INDUSTRIAL POLLUTION PROBLEMS

Dissolved Oxygen

Australia is a major exporter of food products on a world wide basis. Two

of the major Australian exports are sugar and meat products. Both of these industries produce wastes which are high in BOD and produce a heavy oxygen demand in waterways. Treatment can reduce this demand but it is usually still greater than that which would occur naturally. Secondary treated sewage also produces an oxygen demand in waterways and can contribute to dissolved oxygen reduction in a similar manner to those wastes mentioned above. This means that particular care is necessary in Australian inland waterways which have limited flow and therefore limited capacity to handle oxygen demanding wastes.

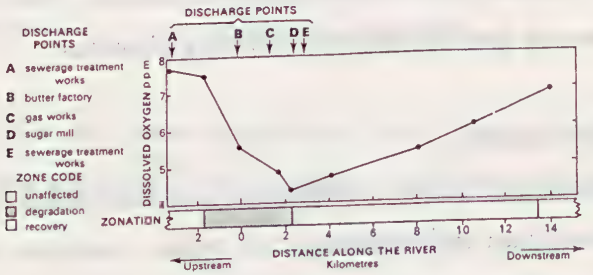

Fig. 1. Dissolved oxygen profile of the Burnett River, Queensland, in May 1967 (Henry 1967).

However, some of the major problems in dissolved oxygen control in Australia occur in coastal streams. Perhaps these are most evident in Queensland which has a high proportion of the sugar and meat industries (Connell 1981). Fig. 1 is an example of oxygen demand in the Burnett River in south Queensland where the Queensland Water Quality Council has measured dissolved oxygen reduction due to industrial discharges. In addition to the industries mentioned above, urban runoff can have high BOD levels particularly after periods without rainfall (Connell 1981).

Eutrophication and Siltation

Many urban streams receive nutrients and silt from urban runoff as well as treated and partly treated food processing wastes and sewage. As a

result of these discharges aquatic plant growth is stimulated and streams become overgrown with benthic plants. Increasing use is being made of urban streams for recreational purposes, particularly now that transport costs, through increasing fuel costs, are increasing. Many areas are used by children for recreation in the urban areas of Australia despite the presence of signs indicating that the streams are unsuitable for swimming.

Petroleum Hydrocarbons

Petroleum hydrocarbons in urban waterways can occur as a result of spills from shipping or discharges from industrial operations. These occurrences have a detrimental effect on recreational usage and conservation of these areas (Connell and Miller 1981). However, in quantitative terms much larger quantities of petroleum hydrocarbons originate from sewage and urban runoff. Petroleum occurs in low concentrations in these discharges but because of the large quantities of discharge involved comparatively large amounts of petroleum hydrocarbons are produced. The petroleum hydrocarbons contain a variety of chemical substances, particularly polyaromatic hydrocarbons (PAH) which have powerful biological activity. This group of compounds are generally toxic to aquatic life and are powerful carcinogens (Neff 1979). Aquatic birds in the Brisbane River estuary have been shown to accumulate high concentrations (up to 1038 ppm) of petroleum hydrocarbons present in low concentrations in water and sediments (Miller and Connell 1980).

Polychlorinated Biphenyls (PCB's)

These are a group of chlorinated hydrocarbons which have been used in a wide variety of industrial applications from lubricants to transformer fluid (Hutzinger *et al.* 1977). They are very stable compounds and persist for long periods in the natural environment and have deleterious biological effects on living organisms.

The limited information available on the Australian situation (see Richardson and Waid 1982) indicates that PCB's occur most commonly in

waterways in urban areas. A comprehensive investigation has been carried out on the Brisbane River indicating that concentrations up to 2.9 ppm occur in the sea mullet (*Mugil cephalus*), an edible fish, and 15.7 ppm occur in the muscle tissue of pelican (*Pelicanus conspicillatus*) (Shaw and Connell 1980). These concentrations are comparatively high when compared with standards set by the United Nations but their effects on the natural ecosystem are not known at this stage.

The control of these substances presents a difficult problem since it would seem in the case of the Brisbane River that solid waste disposal areas are a major source and in these areas discarded electrical equipment is the origin (Shaw and Connell 1980). It can be expected that electrical equipment containing PCB's will continue to be unwittingly disposed on in this way resulting in contamination of urban areas. Electrical installations which use larger quantities of PCB's have taken precautions against environmental contamination and many of these organisations have large quantities of PCB's in storage awaiting some suitable disposal procedure.

There have been restrictions on the sale and use of PCB's in recent years. Nevertheless, it can be expected, because of their occurrence in older electrical equipment and their persistence that they will continue to be present in Australian urban areas for some years in the future.

Construction of Barrages

Along the south-eastern coast of Australia where the major part of the Australian population lives, the coastal streams are short and flow swiftly from the mountains to the sea. These streams must provide the major source of water for urban and industrial use. Since the streams are short in many areas barrage construction has been undertaken to prevent the entry of salt

water into the impounded area and to provide a large reservoir of fresh water. The construction of barrages can be expected to continue along the east coast of Australia since demands for water will increase. However, the construction of barrages results in a major impact on the streams where this occurs.

In many cases the barrages are constructed upstream of urban complexes so as to protect the impoundment from sewage and urban wastes. However, the discharge of these wastes into the urban section of estuaries which have been barraged can result in major water quality problems. The barrage construction principally causes a decrease in water flow through the estuary and thus a decrease in the flushing of discharged wastes out of that area. Many of the estuaries which have been barraged have not been subject to intensive study but the Fitzroy River estuary has a barrage and can be taken as being indicative of some of the water quality problems which may result. During periods of low flow there is an increase in nutrients arising from sewage and industrial discharges in the vicinity and increased phytoplankton growth as indicated by chlorophyll concentrations (see Fig. 2.). Thus the construction of barrages poses a major water quality management problem for streams along the east coast of Australia.

SOME SCIENTIFIC ASPECTS OF THE MANAGEMENT OF URBAN AND INDUSTRIAL DISCHARGES

Physico-chemical Standards

Physico-chemical standards play a major role in the management of water quality on a worldwide basis. Hart (1974) has reviewed the criteria which can be used in setting physico-chemical standards for Australian waters. Much of the data which is available is derived from investigations in North America

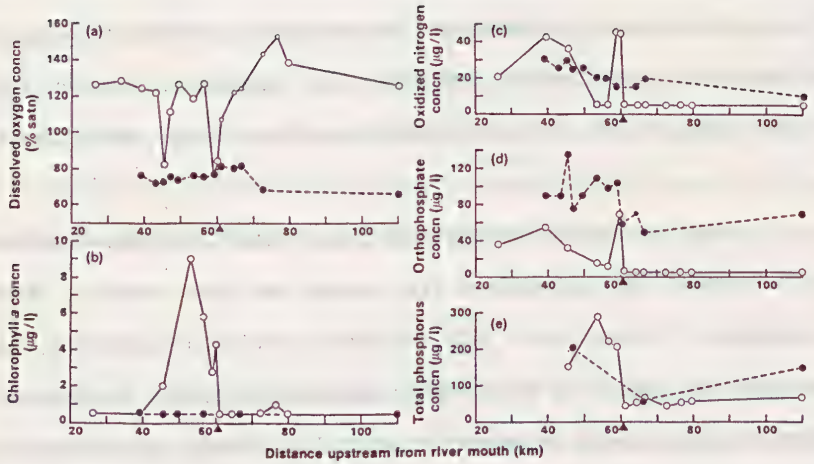

Fig. 2. Changes in water composition with distance upstream from the river mouth in the Fitzroy River, Queensland. (a) Dissolved oxygen concentrations; (b) chlorophyll *a* concentration; (c) oxidised nitrogen concentration; (d) orthophosphate concentration; (e) total phosphorus concentration. ——— Low discharge conditions. ------ High discharge conditions. ▲ Barrage.

and Europe. It is likely that much of this data may be appropriate for southern Australia, i.e. Victoria, Tasmania and southern New South Wales, where seasonal conditions and water temperatures are somewhat similar to North American and European situations. But there may be difficulties in applying the criteria in other parts of Australia where environmental conditions show some marked deviations from the areas where the criteria were developed. Some of these different factors are outlined below.

(i) Seasonal Rainfall Pattern: Northern Australia has a marked seasonal pattern of rainfall in which most rain falls during the summer period and there is winter drought. River flows show the same corresponding variation. Since the discharge of urban and industrial wastes is dependent on dilution by river water for the most effective disposal, seasonal variations in rainfall need to be taken into account in managing discharges in Northern Australia. Thus criteria set for a more persistent pattern of flow throughout the year may not be appropriate.

(ii) Differently Adapted Animals: Lake (1971) has reported that because of the seasonal patterns of flow in many Australian rivers, dissolved oxygen stress often occurs under natural conditions during the low flow period. Fish in these areas have shown a wide variety of special adaptations to low dissolved oxygen concentrations. This factor may need to be taken into account in developing dissolved oxygen criteria for those parts of Australia.

(iii) Higher Water Temperatures in Northern Australia: Investigations in Florida, which has a somewhat similar latitude to south Queensland, have indicated that many aquatic organisms in tropical and sub-tropical areas are close to their upper thermal tolerance limit (Thorhaug *et al.* 1978). Thermal discharges in some of the situations investigated have only resulted in small increases in temperature but caused wide mortalities of aquatic organisms since the upper thermal limit was exceeded. It would be expected that similar situations would occur in Australia.

(iv) Dissolved Oxygen Concentrations: As a result of higher ambient temperatures in northern Australia it can be expected that the dissolved oxygen concentrations will be correspondingly lower. In addition, because of the higher temperatures, aquatic organisms will exhibit higher metabolic rates and thus a higher consumption of dissolved oxygen. These two factors acting together can result in a narrow limit between the existing oxygen concentration and the lethal dissolved oxygen level for aquatic organisms. Thus overseas criteria for dissolved oxygen may be unsatisfactory in northern Australia.

Another factor which may be important here relates to the growth of mangroves along the banks of many Australian streams. This productivity will be substantially contributed to the bottom sediments in the form of leaf litter fall. Investigations in Norman Creek in the Brisbane area (Connell *et al*. 1982) have shown that this stream, typical of coastal mangrove fringed streams on the east coast of Australia, suffers from oxygen stress from benthic demand (see Fig. 3). Thus mangrove lined creeks, incorporating anaerobic sediments, may require special dissolved oxygen management procedures.

(v) Toxic Substances: There is an extreme shortage of knowledge of the lethal and sub-lethal effects of industrial chemicals on Australian aquatic organisms.

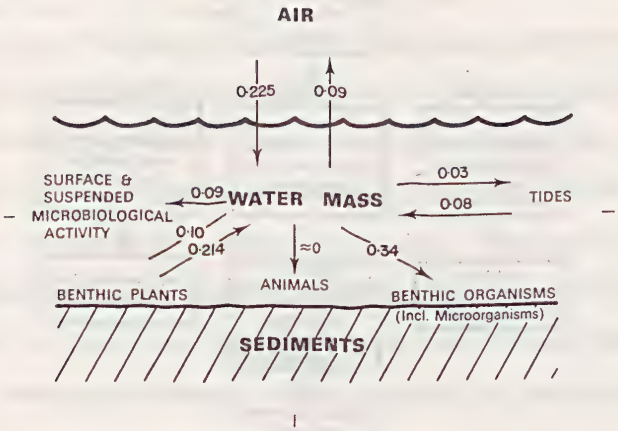

Fig. 3. Oxygen flows per day (in grams of $O_2 \times 10^6$) measured in Norman Creek, Brisbane. (Connell *et al.* 1982).

Biological Standards

A variety of biological procedures are used in the assessment of the effects of discharges on aquatic areas. We have completed an investigation recently of Bulimba Creek in Brisbane where the relationships between physico-chemical and biological characteristics and their application to water quality management were investigated. This indicated that the two methods are suitable for different objectives and in fact are complementary. The physico-chemical procedures have applicability in water quality management for domestic, agricultural and industrial purposes. The biological procedures involve the use of a variety of diversity indices and evaluations of biological communities in general and are more suitable for long-term evaluation of the health of an urban aquatic area (Arthington *et al.* 1982).

ADMINISTRATIVE PROCEDURES AND MANAGEMENT

An idealised outline of the procedures for administering and managing pollution is set out in Fig. 4. The most socially beneficial long-term pollution control procedures requires sets of ecological, social, economic

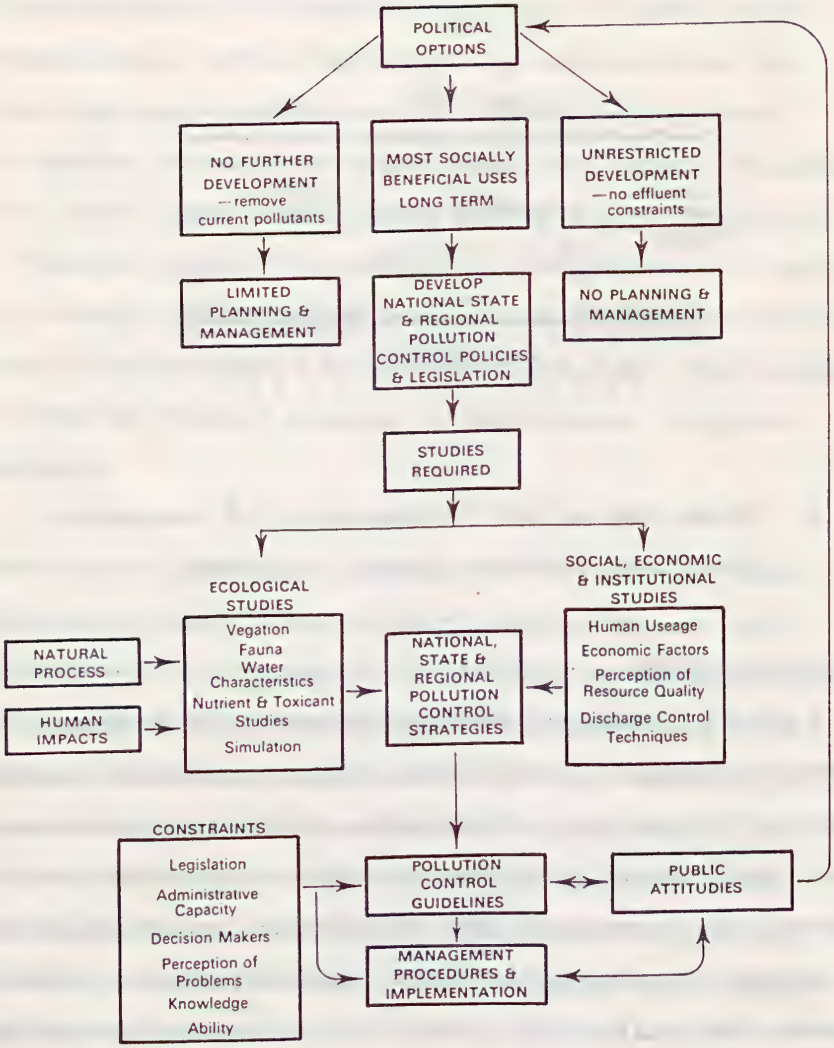

Fig. 4. Idealised process for the control and management of water pollution.

and institutional studies carried out according to objectives in accordance with the overall framework of politically developed policies and legislation. On this basis pollution control guidelines for industry can be formulated and implemented by Government instrumentalities. There are constraints on the success of this implementation which relate to the nature of the legislation, knowledge and ability of the agency staff and so on. The impact of the implementation procedures influences the public, industry and interest groups which in turn feeds information into the political process thereby ultimately resulting in changes and modification to the pollution control guidelines.

The Australian Federation of States has a division of responsibilities between the Federal Government and State Governments such that local matters are left to the states and international and national matters remain with the Federal Government. In water quality management the State Governments are responsible for day-to-day management and licensing of discharges but there is a need for a national approach on a number of matters. Briefly a national approach is needed to identify national water management problems and to initiate research for their solution. In addition, co-ordination of licensing of discharges between the states is needed.

CONCLUSIONS

A national consultative body with natural scientists, engineers and social scientists, as well as water managers, is needed to advise on national priorities and policies in water management in freshwater and inland water bodies as well as estuaries. The national consultative body should develop policies on raising funds from water users throughout the country, perhaps in a similar manner to that used with wheat, wool and other primary products.

The primary organisation to carry out recommendations made by the national consultative body should be a National Water Research Institute, having the following objectives:

(i) To provide a national data bank developed from existing information both within Australia and overseas, on all significant aspects of water development usage, and protection in Australia, particularly in terms of domestic and stock use, recreation, health and conservation of natural ecosystems.

(ii) To undertake research on the matters identified as significant national problems by the national consultative body.

(iii) Stimulate water research in areas identified by the national consultative body in Universities, Colleges and other state and commonwealth instrumentalities as well as private bodies as considered appropriate.

The functions of monitoring and licensing of discharges should remain with the state government instrumentalities as occurs at present. It is noteworthy that national institutes for water research are well established in many countries elsewhere in the world with fewer water quality problems than Australia. The Senate Select Committee on Water Pollution (Davidson *et al.* 1970) made a somewhat similar recommendation but no action has been taken on this matter up to the present time.

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THE IMPACT OF MINING ON FRESHWATERS ' ECOSYSTEMS

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ABSTRACT

Mining can have a considerable environmental impact which extends far beyond the boundaries of the operation itself. This is particularly true when emissions into freshwater ecosystems are considered. However, mining and the associated processing of minerals has been taking place for some time without extensively devastating any biological systems. The natural resilience of eco-systems has long been overlooked, and the concepts of contamination and pollution, which is the excess contamination over the capacity of the ecosystem to absorb it, are discussed.

The environmental impact of some of the more dangerous contaminants from mining is discussed, and some examples, both good and bad, of Australian mining operations are presented.

The role of the freshwater biologist in determining and reducing the environmental impact of mining operations is also discussed.

INTRODUCTION

Man has known about contamination of natural waters near mining operations for centuries. In the mid-sixteenth century, Georgius Agricola wrote in an early textbook of mining in Germany: "...when the ores are washed, the water that has been used poisons the brooks and streams and either destroys the fish or drives them away...". He also referred to early Italian legislation forbidding mining in fertile fields, vineyards and olive groves. In 1791 concern for the environment was expressed in a British coal mining lease where it was written that, after closure of the mine, the shaft was to be filled up and "sown with rye grass seeds". In 1884 some British rivers were said to be polluted, especially as a result of mining.

However, it is only in the last two decades has man achieved a real understanding of how the contamination from mining operations occurs. It was only in the early 1970's that books on the environmental impact of mining began to appear.

When I talk of mining, I mean the whole range of mineral production activities, from mining of ores, through their concentration or refining to ultimate smelting into the pure metal. At all stages of this operation there is the potential for contamination of the environment.

You will have noticed that so far I have only talked about contamination, and have not yet used the catch-all term "pollution". What exactly is pollution? The Victorian Environment Protection Act defines this as "any direct or indirect alteration of the physical, thermal, chemical, biological, or radio-active properties of any part of the environment by discharging, emitting, or depositing wastes so as to affect any beneficial use adversely, to cause a condition which is potentially hazardous to public health, safety or welfare, or to animals, birds, wildlife, fish or aquatic life, or to plants or to cause a contravention of any condition, limitation, or restriction to which a licence under this Act is subject".

The second part of this definition, from "affect any beneficial use adversely...", assumes that we know the level of contamination which is harmful. Conversely, I ask just how much contamination can the environment absorb without coming to any harm. We must be realistic about environmental contamination. It will occur no matter what attempts are made to contain it. What we must be concerned with is the severity and the impact of this contamination.

I prefer therefore to talk of three stages of environmental purity. Any environment in its "natural" state, can be said to be at a background level. Addition of any substance at a level which is not demonstrably harmful to an environment is "contamination". Any contamination in excess of the capacity of the ecosystem to absorb it without ill effects is "pollution".

Contamination only becomes pollution when we can <u>demonstrate</u> adverse effects on an ecosystem or its components, and it is through the measurement of contamination, and detection and reduction of pollution that the relatively new science of environmental management has arisen.

HOW SERIOUS IS MAN - MADE CONTAMINATION

Nevertheless, we must put contamination by man in perspective. Nature is by far the largest contaminator and even pollutor of the world today. Consider the situation where, in less than an hour, the top 400 metres of a mountain was blown off in a massive eruption that took dozens of lives, devastated nearly 500 square kilometres, triggered destructive floods and mudflows, and sent ash clouds rolling around the world. Almost two million birds, fish and animals perished, and more than 240 kilometres of trout and salmon streams and lakes were destroyed. This was of course Mount St. Helens in May 1980. Some 400,000 tonnes of sulphur dioxide, more than that emitted in a year by a very large metal smelting complex, was released almost instantaneously. And the Mount St. Helens eruption is regarded as minute compared to the explosions of Krakatoa and Indonesia's Tambora in the nineteenth century.

The mining industry is often highlighted as a significant source of environmental contamination. While not seeking to excuse the industry, this reputation is sometimes not justified. Nevertheless contamination, and often pollution, does occur as a result of mining. I believe the industry is starting to realise this and has done exceptionally good work to contain and reduce this contamination, especially in operations begun in the last five years.

ENVIRONMENTAL IMPACTS OF MINING

In order to be able to reduce contamination from mining, we must first identify the sources of this contamination. Unfortunately these are many and varied, and depend to a considerable extent on the type of mineral being mined and the processing it then undergoes. In broad terms the environmental impacts from mining and mineral processing operations can be identified as shown in Table 1.

Of the various contaminants listed, I would like to spend a short time discussing those I believe have the greatest potential for pollution - pH alteration as a result of seepage or acid rain, and heavy metals.

Acid rain (or, more correctly, acid deposition, which encompasses dry as well as wet acidic substances) is, fortunately, a source of freshwater contamination that has not yet reached Australia. However, it is a problem currently causing considerable concern in Europe and North America. The problem of acid deposition starts, most experts agree, with the worldwide burning of coal, oil, and natural gas. Despite general adherence to existing environmental controls, the smokestacks of electrical generating plants, industrial boilers, and smelters release sulphur dioxide and nitrogen oxides, the chief precursors of acid rain. These are eventually captured within clouds or by raindrops and snowflakes to form acid rain and snow - which in reality are dilute solutions of nitric and sulphuric acids.

Table 1 Environmental impacts on aquatic ecosystems of mineral production

PRIMARY PRODUCTION	
Solid material	
Seepage from tailings areas	
Heavy metals in mine water	
Fuel, oil and hydraulic fluid spills	
pH alteration	
Water table changes	
SECONDARY PRODUCTION	
Iron and Steel	
Pickling acids	Suspended solids
Phenols	Cyanides
Heavy metals	Phosphates
Heat	
Copper, Lead, Zinc and others	
Suspended solids	Heavy metals
pH alteration	Acid rain
Flotation chemicals	

After Butt (1981)

However, the pattern of effects of acid rain is often difficult to interpret, due mainly to the buffering capacity of water and soils on which it falls.

THE SUDBURY EXPERIENCE

Interestingly enough, well intended Government regulations, especially in the United States, have aggravated the problem. Environmental Protection Agency rules promulgated in 1970, aimed at reducing ground level concentrations around sources of sulphur and nitrogen oxides, resulted in many plants increasing the size of their stacks. The record stack, a 380 metre giant at the INCO nickel smelter in Sudbury, Ontario, also holds the record as the free world's single greatest source of sulphur dioxide - 900,000 tonnes per year (albeit a welcome reduction from the 2.6 million tonnes in earlier years). Using sulphate concentration as an index of contamination, the area subject to severe pollution extends about 6 to 8 kilometres from the three smelters in the Sudbury region. Much of this zone is essentially dead, in biological terms. The aquatic flora in lakes in the immediate vicinity of Sudbury has been drastically reduced, both in terms of diversity and productivity. These lakes also show considerably elevated levels of heavy metals (Table 2).

Table 2 Chemical and Biological Composition of Representative Lakes around Sudbury, Ontario

Distance from smelter (km)	pH	SO_4	Cu (ppm)	Ni	Phytoplankton (cells/ml)
2.0	6.3*	275	0.06*	6.4	negligible
2.4	4.1	72	0.52	2.7	negligible
4.0	6.1	48	0.20	0.4	144
6.4	6.4	40	0.005	0.15	740
11.6	6.7	25	0.003	nd+	1154

\+ Not detectable

* Possibly due to higher buffering capacity of Lake

Adapted from Whitby *et al.* (1976)

The combination of high copper and nickel is likely to be especially harmful to living organisms, since it has been shown that copper and nickel act synergistically in their toxicity to algae and that this synergism is increased at low pH levels. However, isolates of *Chlorella* and *Scenedesmus* from the metal-polluted Sudbury lakes have been shown to be tolerant of copper and nickel levels which are inhibitory and toxic to closely related laboratory strains.

Similar results have recently been found in Cornwall, U.K., where algal species tolerant to heavy metals have been found. Depending on the species, this tolerance is either pre-existing or appears to have developed as a result of selection pressure. Some species show co-tolerance; for instance a species growing in a site polluted with copper may also be tolerant to lead, although no lead is present in its environs. A very few species seem to have a non-specific resistance to metals, due to a mucilaginous secretion which can bind heavy metals and render them harmless.

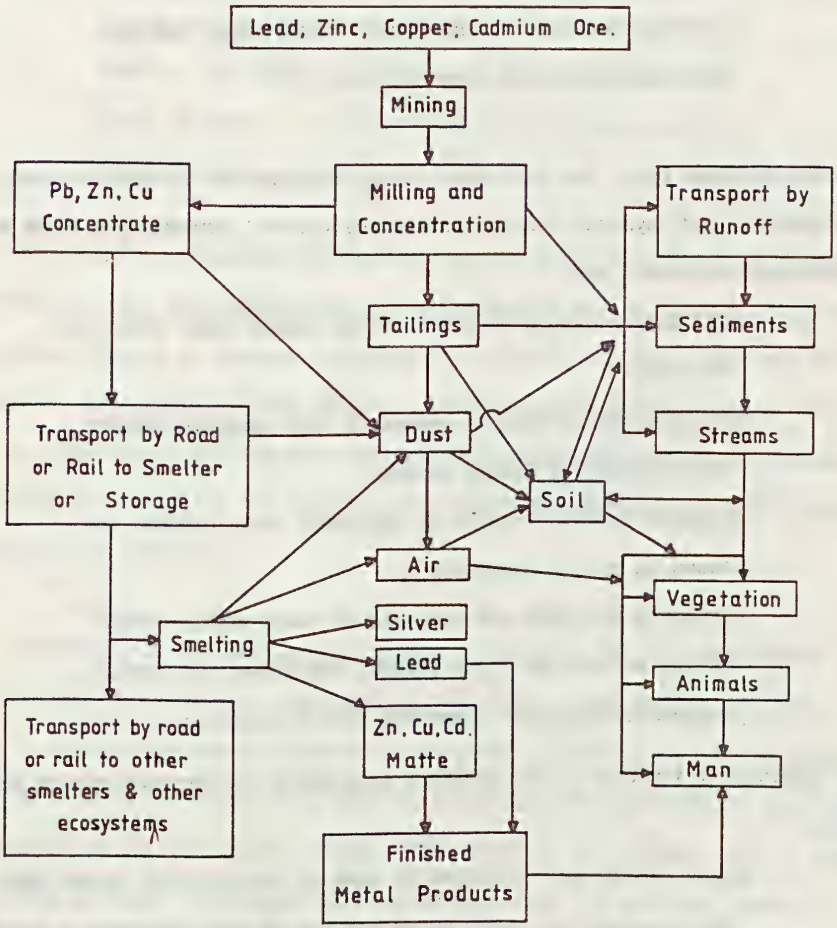
A UNITED STATES EXAMPLE

As to be expected, the best documented studies of the effects of heavy metals on the environment have been carried out in the United States. I have selected one of these as an example of how intensively an aquatic ecosystem has been studied.

The Vibirnum Trend, or New Lead Belt, of Missouri is a rich lead-zinc deposit 64 kilometres long and since 1970 has ranked first in the world in lead ore production. There are a number of mines and mills and one smelter associated with this mineralisation, some of which have been operating since the turn of the century. Through the work of many scientists the paths of trace metals into the general environment have been traced (Jennett *et al*. 1977). As can be seen in Fig. 1, these are many and the end result is extremely complicated.

Fig. 1

SOURCE OF TRACE METALS IN THE ENVIRONMENT OF THE NEW LEAD BELT OF S.E. MISSOURI



From Jennett et al.(1977)

The major sources of lead emissions from the operations, which can in fact be generalised to most mining operations, are:

- smelter stack
- fugitive emissions (transport, windblown dust)
- mine water (from dewatering)
- mill water (spills etc.)
- tailing (solids or seepage)
- concentrates (blows and washing)
- miscellaneous smelter emissions (storm water lagoons, acid neutralisation systems etc.).

In the New Lead Belt, the most significant differences in the observed values of chemical and physical characteristics of control streams and those receiving industrial effluents are:

- turbidity and suspended solids are higher near industrial outlets;
- mine and mill effluents generally have markedly higher Total Dissolved Solids levels;
- periodic elevated levels of phosphate and nitrogen are found in stream segments;
- virtually all high measurements of heavy metals occur during periods of storm runoff, and these are mostly associated with the suspended solids fraction.

The biological impacts of the effluent from mills and process mining water have been:

- algal blooms have occurred in some of the tailing ponds used for treatment of waste water and for several kilometres below the discharge point in receiving streams;
- diversity index values in effluent receiving streams were quite low, but have begun to recover since pollution control systems have been introduced;

- there has been significant bioconcentration of heavy metals. Quantities of lead associated with aquatic vegetation have exceeded 74 000 micrograms per gram (dry weight) at the point of mine water discharge, and more than 8 000 micrograms per gram at the discharge of some tailing ponds;

- considerable quantities of lead and zinc have been found in the gills, mucous membranes and bones of fish. However the fleshy portions of fish likely to be consumed by humans are relatively free of heavy metal contamination.

Despite these impacts, the authors of the study conclude that under present conditions, lead and other dissolved heavy metals do not present a significant biological hazard to aquatic organisms of the New Lead Belt (zinc may be an exception and is still under study). This fortunate circumstance is the result of the alkaline pH and the elevated hardness characteristic of the surface and subterranean waters of the region, combined with pollution control procedures initiated by industry.

Nevertheless the authors add a note of caution, as little is known about the eventual fate of heavy metals over relatively long periods of time. The lead in aquatic vegetation appears to be bound primarily to cell membranes. Most of this can be removed by EDTA in low concentrations without cell rupture, suggesting it is only weakly bound. The sediments of streams, rivers and lakes receiving effluent discharges also serve as a sink for metals. However, the mechanisms of reintroduction of these metals into the aquatic environment are little understood.

In addition, the toxicity of the huge variety of mill reagents (Table 3) is neither fully understood nor appreciated. Few data are available on the toxicity of milling reagents to aquatic organisms, and even less is known about the actual concentrations of residual reagents in industrial effluents. Degradation rates vary considerably and may be affected by pH, temperature, or redox potential of the receiving waters.

There have been some 96-hour median toxicity limits (or 96-hour LC50) published, but these are useful only as an approximate comparison of relative toxicity. They are particularly prejudiced by the obvious shortcomings of short term static toxicity studies. They offer little information regarding toxicity under conditions of continuous flow, nutritional states, long-term effects, nor embryological or teratogenic effects.

Table 3 Reagents commonly used in flotation of minerals

Reagent	Purpose
Methyl Isobutyl-carbinol	Frother
Propylene Glycol Methyl Ether	Frother
Long-chain Aliphatic Alcohols	Frother
Pine Oil	Frother
Potassium Amyl Xanthate	Collector
Sodium Isopropol Xanthate	Collector
Sodium Ethyl Xanthate	Collector
Dixanthogen	Collector
Isopropyl Ethyl Thiocarbamate	Collector
Sodium Diethyl-dithiophosphate	Collector
Zinc Sulphate	Zinc Depressant
Sodium Cyanide	Zinc Depressant
Copper Sulphate	Zinc Activant
Sodium Dichromate	Lead Depressant
Sulphur Dioxide	Lead Depressant
Starch	Lead Depressant
Lime	pH Adjustment
Caustic Soda	pH Adjustment

The most important conclusion of the New Lead Belt study is that the ore concentrator, with its attendant process reagents and finely ground tailing, is the source of the gratest concern for the aquatic ecosystem. The elimination of toxic chemicals and effluent particulate matter from the final tailing pond effluents would ensure minimum adverse effects from the industrial operations on the receiving stream.

Similar results have been found for streams in mining districts of the United Kingdom, although not in the same scale as the United States. In the UK however, another facet of the problem has emerged. Because of the long mining history of the country, in some cases since the Roman Empire, there are numerous examples of abandoned mines and processing operations which result in continued contamination of freshwater systems.

WHAT IS THE AUSTRALIAN SITUATION

In contrast to America and the United Kingdom, we in Australia know comparatively little about the freshwater impact of our mining and milling operations. Perhaps the best documented examples are two operations which were closed down some years ago - Rum Jungle and Captains Flat.

RUM JUNGLE

Between 1953 and 1971, the Australian Atomic Energy Commission supervised uranium mining at Rum Jungle in the Northern Territory (Davy 1975). During this time there was concern that a river near the mines had become polluted as a result of the operation. Measures were taken to remove the apparent causes of this pollution, but after mining had ceased it became evident that contamination was continuing. Subsequent investigation revealed three main sources of this contamination:

- tailings dumps were not constructed to withstand the annual monsoonal rains, so pollutants held in the dump were regularly washed into the Finniss River system;

- overburden heaps which contain sulphur in the form of pyrites; Exposure of pyrites to water and air caused pollution by acid and dissolved metals such as copper;

- the open cuts which filled with water after mining was completed. These soon became polluted with acid and dissolved metals.

It is interesting to note that, although Rum Jungle is best known as a uranium mine, the major contaminants are in fact the other heavy metals associated with the uranium.

Not all mining in the Rum Jungle area caused pollution. For example, very little pyritic sulphur occurred in the overburden of a uranium mine known as Rum Jungle Creek South. The overburden heap from this mine had very little impact on the Finniss River System, and the open cut is now a popular swimming hole for the residents of the nearby town of Batchelor.

The effects of the release of the pollutants from the Rum Jungle operation are:

- two tributaries of the Finniss River support very little aquatic life, as they accumulate pollutants during the dry season. This impact can be detected for about 4 to 5 kilometres from the mine site;

- once a year, fish are killed in parts of the Finniss River by a concentrated body or "slug" of pollutant. This is washed down the river during the first wet season rains;
- fringing vegetation is damaged but not beyond recovery;
- in certain low-lying areas of the Finniss floodplains, grasses contain high concentrations of copper and other metals, especially manganese and zinc. These levels are close to or exceed the maximum recommended levels for livestock feed. However, no evidence of direct adverse effects on animals has so far been found.

The amounts of radium, the most likely radioactive contaminant, absorbed by animals and plants or found in surface soils, are no greater than the levels found naturally in other parts of the Northern Territory.

Partly as a result of the Rum Jungle experience, other potential mining operations in the Northern Territory have been subjected to intense environmental scrutiny. In fact the Alligator River area must be about the most intensively studied patch of land in Australia. Because potential sources of contamination have been identified at Rum Jungle, the Alligator River operations have been planned and regulated in such a way to minimise their environmental impact, and extensive monitoring programs have been established to ensure this is so. In the Northern Territory at least there will not be another Rum Jungle.

CAPTAINS FLAT

Copper, gold, lead and zinc were mined from 1874 to 1962 at Captains Flat, New South Wales, close to the source of the Molonglo River (Anon 1974). The Molonglo is the major water source for Lake Burley Griffin in Canberra.

The first record of investigations into mine waste pollution of the Molonglo River appeared in 1911 (Anon 1974). It showed that acidic water containing 0.086% free sulphuric acid was discharging into the river at 5 to 6 cubic metres per day from a spring at Lake George Mines, Captains Flat. Subsequent to this there is no published record of investigations of mine waste pollution until 1959, although mine dewatering operations would have resulted in the discharge of acidic water into the river from 1925 onwards.

In 1939 a tailing dam burst and tailing and water were discharged directly into the river, resulting in destruction of vegetation along the Molonglo Valley. A similar collapse occurred in 1942, and an estimated 30 000 cubic metres of tailing flowed into the river. Extensive flooding of the Molonglo in 1945 re-deposited some of this tailing further downstream, damaging pastures.

Subsequent to closure of the mines, the major sources of pollution have been identified as:

- erosion and leaching of mine waste dumps;
- mine water flowing from the main "spring" at Captains Flat. This spring drains water from the old underground workings through what is known as the explosives adit;
- river bed sediments high in heavy metals in Copper Creek at Captains Flat and in the Molonglo River downstream (Table 4).

Although there is a considerable bank of knowledge about the chemical and physical effects of the Captains Flat operations, comparatively little is known about the biological effects.

Table 4 Levels of heavy metals at Captains Flat
(All values except pH are ppm)

Element	Southern Dumps	Mine Drainage	Molonglo River	Lake Burley Griffin Sediment
pH	2.8	1.5-2.0		
Zinc	26,000	6,200	130	1,080
Copper	1,000	720	1.5	30
Lead	8,000	70	0.7	71
Cadmium		8	0.03	1.5
Iron		5,000	130	32,000
Sulphur (as FeS_2)	395,000			

Adapted from Craze (1977)

However, the diversity and abundance of aquatic life in the Molonglo River is significantly reduced at Captains Flat. Aquatic life gradually becomes more diverse and abundant downstream and approaches normality just before the Queanbeyan-Molonglo Rivers junction, about 35 kilometres from Captains Flat. Below the junction the ecology of the Molonglo River and Lake Burley Griffin is regarded as normal.

Fish have virtually been eliminated from the upper reaches of the river below Captains Flat. However, at present the levels of zinc and acidity in Lake Burley Griffin are sufficiently low to permit fishing (Anon 1974).

The effects of metals in solution are not the only causes for concern. Preliminary data obtained by the Department of the Capital Territory indicate that concentrations of heavy metals in the tissues of fish and several aquatic

plants in Lake Burley Griffin are in the order of 10 times higher than concentrations in similar organisms in the uncontaminated Queanbeyan River. Cadmium particularly is singled out as being of major concern.

LONG TERM IMPLICATIONS AND POTENTIAL FOR RECOVERY

Both Rum Jungle and Captains Flat have been the subject of extensive public scrutiny, and Government-appointed commissions have proposed remedial action costing many millions of dollars. It is obvious though that in both these cases such remedial action is necessary. Nevertheless, the ability of ecosystems to recover naturally after perturbation is often underestimated. Unfortunately I do not know of any investigations into this in Australia.

There are however, some documented cases of recovery of streams in mining areas, particularly in the United Kingdom. However, the results of these studies show that such recovery is not necessarily swift, and is rendered difficult by the sheer complexity of the physical and biological systems.

A recently documented case was that of a river in Wales, which drains a lead mining district that can be traced back to Roman days (O'Grady 1981). As early as 1884, when the last mine closed, the Rivers Pollution Commission stated that the river was polluted.

Although mining ceased almost 90 years ago, heavy metal contamination from the waste dumps is still evident in the river.

Limited records of the occurrence of animal life show a pattern of upstream migration, presumably as the pollution has abated. The macro-invertebrate population has completely recolonised the entire river up to the spoil heaps, but

the number of species is still lower than baseline. However, the upstream progression of trout is occurring at an ever decreasing rate, despite the reduction in heavy metal contamination.

The authors of this study conclude that full recolonisation of the river was unlikely, unless other factors were interposed on the environment, such as removal of the spoil or reduction of the contamination in some way.

WHAT CAN WE, AS LIMNOLOGISTS, DO?

There are thus two major considerations when we examine the ways of reducing contamination and pollution from mining and mineral processing operations.

The first is what should we do to abandoned and existing operations which were planned in the days when there was neither the knowledge nor the concern which exists today. There are numerous ways of "cleaning-up" operations - some of these are shown in Table 5. Unfortunately all of these cost money, and this money is not always readily available. For abandoned mines, the problem is even worse. The bill for the partial cleanup of Captains Flat was $2.5 million, with a continuing maintenance cost of $200,000. For Rum Jungle the bill now exceeds $16 million.

Therefore there must be some way of assessing the priorities for cleanup of such operations, and it is here that the limnologist can play an important role. It is not sufficient to show that an old operation is causing contamination; we should be looking for and refining methods for delineating pollution as distinct to contamination, as I defined earlier. In such a way the number of culprits should be reduced, hopefully to a more manageable number.

Table 5 Some corrective measures for reducing contamination from mining operations

Primary Mineral Production
. Effective reclamation
. Better design of tailings areas
. Mine water treatment
. Improved operating procedures
Smelting and Refining
. Recovery of SO_2 and particulates
. Effluent treatment
. Improved pollution control equipment
. Process water recycling and treatment
. Process change

Adapted from Butt (1981)

In fact we should be able to go even further and put priorities on these operations based on the severity of the pollution as revealed by the biological investigations. However, as Sam Lake pointed out in last year's presidential address, experimental limnology such as this is virtually non-existent in Australia (Lake 1981).

New operations, on the other hand, are generally designed to meet or better existing environmental standards and therefore ideally should not result in pollution. Nevertheless, without adequate control procedures we cannot always be sure that they continue to meet the standards. Here the aquatic biologist must work to develop simple but effective techniques to monitor systems which may be affected by such operations. John Cairns Jr. has attempted to do this in the United States, but in many cases the techniques are difficult to transfer to Australian conditions.

I believe therefore that the opportunities for the limnologist are many, but it will be up to us to put ourselves forward. Government administrators and Company managers share a reluctance to seek out and promote research which, although expensive in the short term, may save them considerable sums of money in the future. It is up to us to show them how these savings can be achieved.

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